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Heavy metal contamination of river Yamuna, Haryana, India: Assessment by Metal Enrichment Factor of the Sediments

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ABSTRACT

Concentration of Heavy Metals (Cd, Cr, Fe, Ni) in water, plants and sediments of river Yamuna flowing in Haryana through Delhi are reported here selecting 14 stations covering the upstream and downstream sites of major industrial complexes of the State. Some important characteristics of river water and sediments (pH, EC, Cl^-, $SO_3{}^{2-}$, and $PO_4{}^{3-}$ in water and sediments, COD of water and organic matter content of sediments) were also analysed and inter-relationships of all these parameters with heavy metal concentration in different compartments were examined. The sediments of the river show significant enrichment with Cd and Ni indicating inputs from industrial sources. Concentrations of Cr are moderate and show high enrichment values only at a few sites. Enrichment factor for Fe is found to be <1, showing insignificant effect of anthropogenic flux. Concentrations of these metals in river water are generally high exceeding the standard maximum permissible limits prescribed for drinking water, particularly in the downstream sites. The aquatic plants show maximum accumulation of Fe. The other heavy metals Cd, Cr and Ni, though less in concentration, show some accumulation in the plants growing in contaminated sites. Interrelationships of metal concentration with important characteristics of water and sediment have been analysed. Analysis of heavy metals in water, sediments and littoral flora in the stretch of river Yamuna is first study of itself and interrelationship of metal concentration and other important characteristics make the study significant and interesting in analysing the pollution load at different points of the river body.

1. Introduction

Rapid industrial development in the last few decades has added huge loads of pollutants to our rivers [1]. Out of these pollutants, heavy metals are of major concern because of their persistent and bio-accumulative nature. These heavy metals may be of geological origin entering into the river system by weathering and erosion [2] or anthropogenic due to mining, industrial processing, agricultural run-off and sewage disposal [3]. In the aquatic system a rapid removal of these heavy metals from the water to sediments may occur by settling particles while some of these pollutants can be mobilized by getting accumulated into the biota from the sediments sink [4].

In a developing country like India, where most of the developmental activities are still dependent upon rivers for cleaning as well as disposal purposes, it becomes very important to systematically study the status of pollution of the rivers in relation to various anthropogenic activities. Yamuna is a major river of India, originating from the Yamnotri glacier near Banderpunch Peak of the lower Himalayas (38°59′N 78°27′E) in the Mussorie range at an elevation of about 6320 m above mean sea level in the Uttarkashi District, Uttaranchal. The catchment of the river with an extensive area of about 3.5×10^5 km^2 covers several states out of which Haryana has a catchment area of about 2.1×10^4 m^2 [5]. The river has a stretch of about 224 km in Haryana from Hathnikund to Palla, after which it enters Delhi and traverses a distance of approximately 22 km and re enters Haryana in Faridabad district covering another 100 km distance in Haryana before entering the state of Uttar Pradesh. Thus, Haryana is both the upstream and downstream state with respect to Delhi for river Yamuna. Most of the industrial growth in Haryana has taken place on the banks of river Yamuna. Although several studies on water quality and heavy metal concentration in Yamuna in Delhi and UP have been carried out [6–9] little attention was paid on the river water quality in Haryana. The authors gave the first report on the dynamics of physico-chemical characteristics of the river Yamuna in Haryana in relation to anthropogenic activities [10]. The authors also reported on some heavy metals in the river water and canals originating from the river in Haryana [11,12]. However, it was observed that in some sampling sites, in spite of high

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pollution, the heavy metal concentrations in the river water were relatively low. Since transfer of these heavy metals can take place by partitioning among different components, it becomes absolutely essential to determine the metal concentrations in the sediments and the aquatic biota as well. It is also important to examine the metal concentration in relation to various other parameters that may affect metal solubilization, precipitation, accumulation and mobility (Force et al, 1998 [13]; Khan et al, 1998 [25]).

The present study was, therefore, undertaken to examine the concentrations of four heavy metals Cd, Cr, Fe and Ni in water, sediments and plants growing in the water of river Yamuna. Inter-relationships of these heavy metal concentrations in different components as well as with some other important water and sediment properties were also studied.

2. Materials and methods

2.1. Sampling

Sampling of different components of the river Yamuna was done in March 2000 from 14 sites all along the route of Yamuna in Haryana through Delhi representing the upstream and downstream stations for main industrial complex of the state. During the sampling period overall climatic condition was a little cloudy followed by minor rainfall at some locations. The site locations are shown in Fig. 1 and site specifications are depicted in Table 1.

Grab samples of water were collected in high grade plastic bottles (2 L capacity) in triplicate and mixed to get a composite sample for each site. All the sample bottles were stored in iceboxes till brought to the laboratory for analysis. Surfacial sediments were collected (0–15 cm depth) by using 7.6 cm diameter gravity steel corer with a tube length of 15 cm. The corer full of sediment was covered with a steel strip to avoid any loss of fine sediment particles on which the heavy metals are adsorbed. Five samples were taken from each site, which were homogenized and the composite samples were stored in high grade Teflon-bottles. The samples were oven dried and powdered in a pestle and mortar prior to analysis. Composite samples of plants growing in the river water just inner to the riverbank were collected randomly as five replicates from each site and stored in paper bags. Complete plants (shoot and roots) were oven dried at 80 °C for 24 h and powdered in a laboratory Wiley mill to pass through 40-mesh sieve.

2.2. Heavy Metal Analysis

Acid digestion of all the samples was done using HNO_3 for minimizing the interference by organic matter prior to estimation of the heavy metals. Acid digestion for water, sediments and littoral flora has been carried out in following way:

Water samples: 100 m of the water sample was added with 20 ml 1:1 HNO_3.
Sediment samples: 1 gm of air dried sample was added with 20 ml 1:1 HNO_3 and 5 ml 37% HCl.
Flora samples: 1 gm of oven dried powered sample mixed with 20 ml concentrated HNO_3 and 5 ml of $HClO_4$.
The above acid digested samples were heated at 80 °C on water bath till dryness and were added with some double distilled water and filter through Whatman no. 42 filter paper and final volume of the sample was made 50 ml with double distilled water.

Analysis of heavy metals was done by atomic absorption spectrophotometer (PerkinElmer 3100) using acetylene gas as fuel (at 8 psi) and air and nitrous oxide as supporting gases. AR grade pure metals and metal oxides were used for preparation of the standards [14].

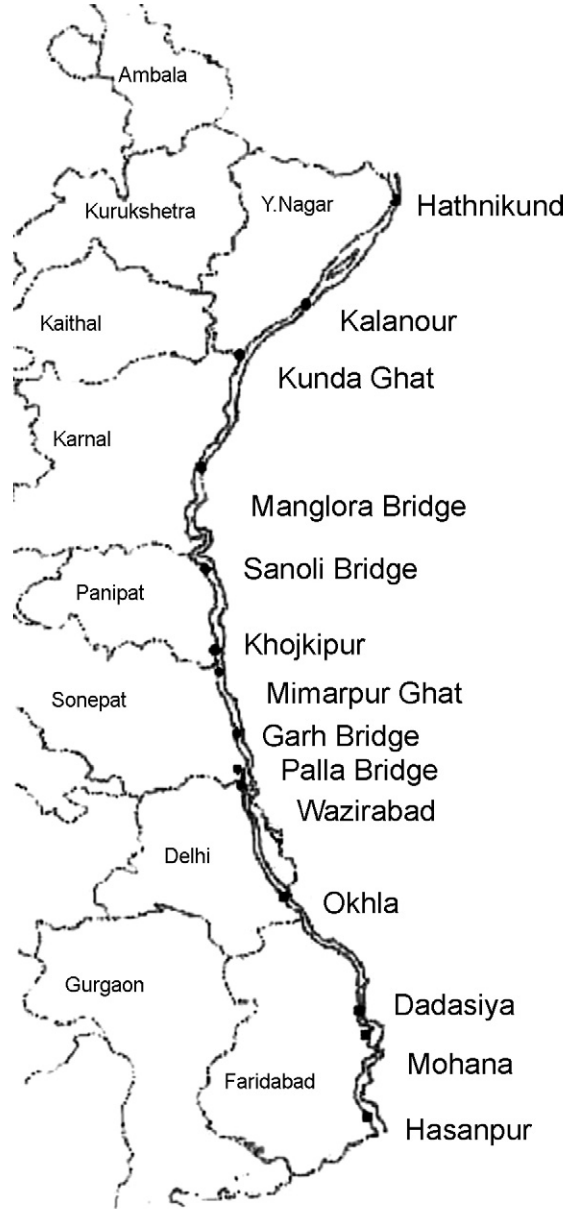

Fig. 1. Sampling stations along the river Yamuna.

Enrichment factor for each of the heavy metals in the sediments was calculated based on the background value of the metal taken as a world average of the metal in soils.

2.3. Water and Sediment Property Analysis

Water samples were analysed for pH, electrical conductivity (EC), Cl^-, SO_4^{2-}, PO_4^{3-} and COD and the sediments were analysed for Cl^-, SO_4^{2-}, PO_4^{3-} and organic matter. Measurements of pH and EC were done using Eventech Cybernetics Model pH meter and conductivity meter respectively, Cl^- by argentometry, SO_4^{-2} by nephalometry and PO_4^{-3} by molybdenum blue complex formation using spectrophotometric method. COD of water was estimated by reflux titrimetry. All the reagents used were of AR-grade and quality assurance and quality procedures were used as described by [14]. For analysis of organic matter in sediments,

Table 1
Description of Sampling Sites all along the river Yamuna flowing in Haryana and Delhi

S. No.	Station code	Name of sampling station	Distance from Hathnikund (in km)	Remarks
1.	Y-01	Hathnikund	00.00	At the fool hills of Shivalik range of Himalayas (170 km from origin of river Yamuna)
2.	Y-02	Kalanor (Yamuna Nagar up stream)	41.00	Industrial area no. 1
3.	Y-03	Kundaghat (Yamuna Nagar down stream)	62.00	Agricultural area
4.	Y-04	Manglora Bridge (Karnal)	107.00	Agricultural area
5.	Y-05	Sanoli Bridge (Panipat up stream)	150.00	Agricultural area (waste water disposed off through drain no. 2 of industrial area-2)
6.	Y-06	Khojkipur (Panipat Down Stream)	164.00	Agricultural area (waste water disposed off through drain no. 2 of industrial area-2)
7.	Y-07	Mimarpur Ghat (Sonepat up stream)	184.00	Agricultural area (Waste water disposed off through drain no. 6 and 8 of industrial area-2)
8.	Y-08	Garh Bridge (Sonepat)	200.00	Industrial area no. 3 (waste water disposed off through drain no. 4)
9.	Y-09	Palla Ghat (Sonepat down stream)	214.00	Industrial area no. 3 (waste water disposed off through drain no. 4)
10.	Y-10	Wazirabad (Delhi upstream)	225.00	Industrial area no.4 (mixing of waste water of Delhi through Najafgarh drain)
11.	Y-11	Okhla (Delhi Down Stream)	247.00	Industrial area no. 4 (huge foam eutrophication in stagnant water)
12.	Y-12	Dadasiya (Faridabad up stream)	268.00	Industrial area no. 5
13.	Y-13	Mohana (Faridabad down stream)	298.00	Wheat production area
14.	Y-14	Hasanpur	310.00	End of river Yamuna in Haryana

Walkley and Black's Rapid Dichromate Titration method was used [15].

The data were statistically analysed for testing the significance of differences using *t*-test and correlation coefficients were determined using the SPSS 7.5 Software package.

3. Results and Discussion

Concentrations of Cd, Cr, Fe and Ni in the river water, sediments and plants are shown in Figs. 2–5. Concentrations of all the heavy metals are about 100–150 times more in the sediments than in the river water. Concentration of these metals in the plants is also of the order of 10 to 100 times that in water indicating bioaccumulation in the plants.

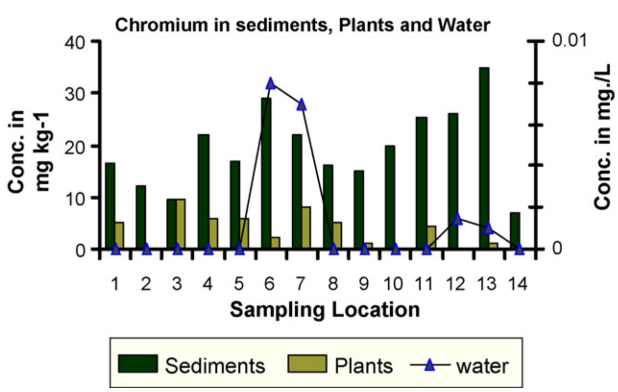

Fig. 2. Chromium in sediments, plants and water.

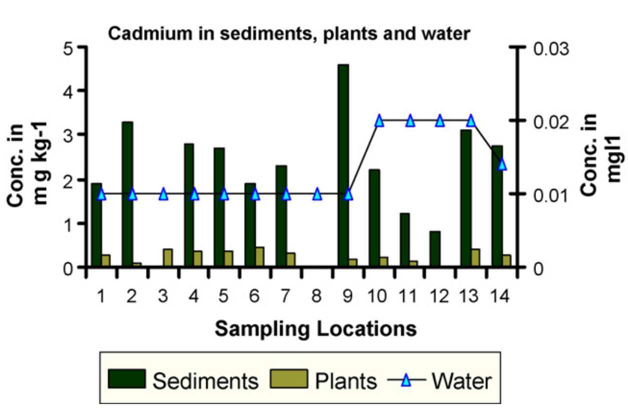

Fig. 3. Cadmium in sediments, plants and water.

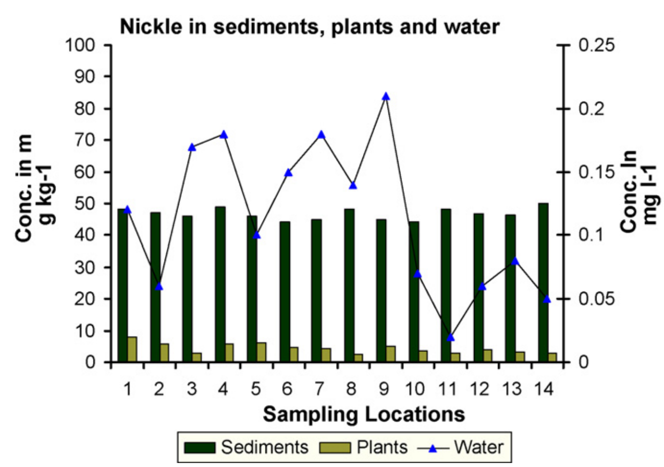

Fig. 4. Nickel in sediments, plants and water.

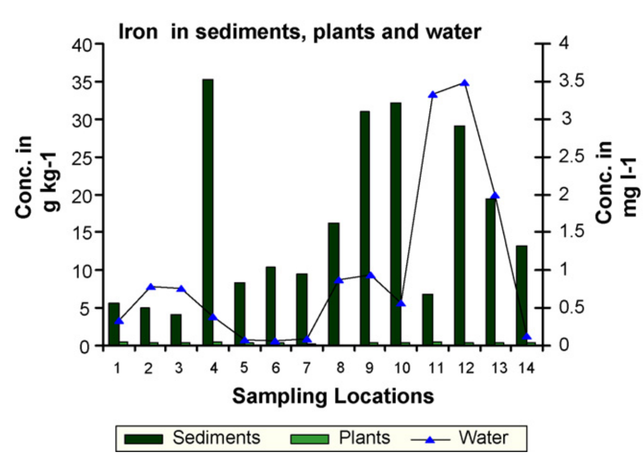

Fig. 5. Iron in sediments, plants and water.

3.1. Cadmium

Concentrations of Cd showed little fluctuations in the river water, ranging from 0.01 to 0.028 mg l^{-1}. The metal concentrations increase in the Delhi segment and Delhi downstream with values of 0.02–0.028 mg l^{-1}. An earlier report of Cd level in Delhi shows much less Cd (0.01 mg l^{-1}) during 1994–1996, which indicates that Cd contamination, has increased in the last few years in this stretch. This may be attributed to several industrial units dealing with engineering goods, textile, chemicals, electrical goods etc. that have come up in this area. The downstream Delhi stretch also shows high Cd levels with additional industrial wastes from the industrial complex of Faridabad–Ballabgarh region.

Cadmium concentration in the sediments was found to be much higher varying from 0.82 to 4.6 mg kg^{-1}. However, in some of the sites (Y-03, Y-08) Cd was below detectable range. The source of Cd could be from the dye and pigment industries, coal-fired thermal power plants, paper mill, fertilizer industry or municipal waste water as evidenced from the high values in the downstream sites of main industrial complexes (Y-02, Y-04, Y-05, Y-09, Y-13, and Y-14).

In general, there is significant Cd enrichment in the sediments of Yamuna in Haryana. However, enrichment factor varies from 2.7 to 15.3 (Table 2), which is quite significant. Maximum Cd enrichment was found at Palla, where no immediate influx of Cd is apparent from any industry or sewage. This indicates some unidentified source other than riverine input causing a high Cd content of 4.6 mg kg^{-1} in this site.

Interestingly, CPCB report of 1981–1982 did not record any traceable Cd in the river sediments while another study [16] reported 0.65–1.75 mg kg^{-1} Cd in the flood plains of Yamuna in Delhi during 1994. The present study conducted in 2000 indicates a further increase of 1.2–2.2 mg kg^{-1} Cd in the sediments of Yamuna in Delhi segment. The Cd enrichment of Yamuna sediments is thus of recent origin. No other record on Cd concentrations in sediments of Yamuna in Haryana is available. Rapid industrial growth along the banks of river Yamuna in Haryana seems to have added to Cd influx in the river.

The aquatic plants show Cd in a range of 0.13 to 0.45 mg kg^{-1}. Thus there is a tendency of bio-accumulation of the heavy metal by the aquatic plants, however, Cd is a non-essential element. Although, some phytoplanktons and hydrophytes have been reported to accumulate upto 2.0 mg kg^{-1} of Cd, but concentrations beyond 1 ppm have been reported to be toxic to the plants [17].

Table 2
Enrichment Factor of different metals in sediments

Sampling station	Cd	Cr	Fe	Ni
Y-01	6.2	1.2	0.13	9.6
Y-02	11.0	0.86	0.11	9.4
Y-03	–	0.68	0.09	9.2
Y-04	9.3	1.57	0.76	9.8
Y-05	9.0	1.2	0.18	9.2
Y-06	6.3	2.1	0.23	8.8
Y-07	7.7	1.6	0.21	9.0
Y-08	–	1.2	0.35	9.6
Y-09	15.3	1.1	0.67	9.0
Y-10	10.6	1.4	0.70	9.8
Y-11	4.0	1.8	0.37	9.8
Y-12	2.7	2.0	0.63	9.3
Y-13	10.3	2.5	0.41	9.2
Y-14	9.2	0.48	0.28	9.9
Background level (mg kg^{-1})	0.3[a]	14.0[a]	46.0[b]	5.0[a]

[a] Alloway, B.J. 1999 [26].
[b] Lo and Fung, 1992 [4].

3.2. Chromium

Concentration of Cr in the river water was quite low and fluctuated very widely. In the upper stretch Cr was not detectable in most of the sites except Y-06 and Y-07 which are down stream Panipat Industrial Complex, having a numbers of textile dyeing industries. Chromium was also present in the waters of Y-12 and Y-13 sites, which is down stream to pottery and ceramics units. Chromium levels in the sediments varied from 6.8 to 35.0 mg kg^{-1} and the sediments of the same sites, which had high Cr contamination in water, showed more chromium contamination. Chromium is a specific pollutant providing evidence of industrial pollution like dyeing or paint operations [4].

Comparing the present Cr concentrations with the average Cr concentrations in different soils, the concentrations in Yamuna are moderate. The mean values of uncontaminated soils range from 1 to 2.5 mg kg^{-1} in different studies [18,19]. Considering the background levels of 14 mg kg^{-1}, the enrichment factor of Cr varied from 0.68 to 1.8 in different sites and only Y-06, Y-12 and Y-13 showing relatively high enrichment factor of 2.0 to 2.5 (Table 2). In the Delhi stretch, Cr concentration has rather been observed to decline in the past. Central Pollution Control Board, Delhi report shows 1–1.8 mg kg^{-1} in 1981–1982 while another study [16] reports 49–108 mg kg^{-1} Cr in Yamuna soils. The present study of 20–25.5 mg kg^{-1} shows a decline in Cr concentrations in the sediments of this region.

The plants show accumulation of Cr in the range of 1.0–8.0 mg kg^{-1}, although Cr is not a micronutrient for the plants. Chromium uptake in some aquatic plants has been reported to range from 1 to 21 mg kg^{-1} in contaminated waters [20].

3.3. Iron

Concentration of Fe ranged from 0.07 to 0.94 mg l^{-1} in the water of upper segment of river Yamuna (Y-01 to Y-09). The concentrations increased many folds in Delhi downstream (Y-11) showing 3.33 mg l^{-1} of Fe. In Faridabad–Ballabhgarh industrial area downstream, the concentration of Fe was again high (3.48 mg l^{-1}). The iron works in Delhi and Faridabad might be contributing to relatively higher values of Fe in the river water in their downstream sites.

Iron concentration in the sediments ranged from 4.15 to 16.2 g kg^{-1} in the Y-09 to Y-12 sites with the exception of Y-11. The values of Fe are much higher than that of the other heavy metals. The world average of Fe in uncontaminated soils is much higher than other metals being 46 g kg^{-1} [21] indicating geological occurrence of this metal in quite high concentrations. Considering such high background levels of Fe in sediments, the enrichment factor for the Yamuna sediments is found to be less noticeable, of the order of 0.11 to 0.70. Thus, despite the fact that utilisation of Fe occurs in large quantities in various domestic and industrial activities, yet the enrichment value is less than 1 indicating insignificant effect of anthropogenic flux of this element into sediments. Similar observations of insignificant Fe enrichment have also been reported [17,21].

Iron is an essential element for plants and the concentrations of Fe in plant leaves were, therefore, much higher (11–487 mg kg^{-1}) as compared to other metals discussed earlier.

3.4. Nickel

Nickel concentrations in water ranged from 0.10 to 0.21 mg l^{-1} in upper stretch, which declined in the Delhi downstream stretch (0.02–0.08 mg l^{-1}). More Ni concentrations occurred in the downstream of Sonepat–Gohana complex (Y-09). The effluents of electroplating industries and cycle industry could be potential

Table 3
Physico-chemical characteristics of sediments of river Yamuna flowing in Haryana and Delhi

Sampling station	Chloride	Sulphate	Phosphate	Organic matter (%)
Y-01	11.27	0.78	ND	0.86
Y-02	6.88	ND	ND	0.10
Y-03	7.51	ND	ND	0.19
Y-04	10.01	ND	ND	0.24
Y-05	7.51	ND	ND	0.28
Y-06	8.13	3.01	0.006	0.11
Y-07	5.01	8.29	0.005	0.05
Y-08	6.88	3.34	0.005	0.11
Y-09	5.63	7.56	0.005	0.26
Y-10	5.63	ND	0.006	0.16
Y-11	5.63	6.68	0.005	0.28
Y-12	5.63	13.36	0.004	0.21
Y-13	6.26	15.15	0.004	0.26
Y-14	5.63	9.8	0.005	1.34
Mean ± S.D.	6.97 ± 1.82	4.86 ± 5.3	0.003 ± 0.002	0.32 ± 0.35

All values in g kg^{-1} (except where mentioned); ND not detectable.

source of Ni in the river. Unpolluted rivers and lakes usually show Ni concentrations in the range of 300 μg l^{-1} to 0.01 mg l^{-1}, while some polluted rivers in India have shown upto.27 mg l^{-1} of Ni [22].

Concentration of Ni in the sediments was quite high, ranging from 45.2 to 49.9 mg kg^{-1}. Variations in Ni concentration in the sediments in different sites along the route of the river are very small. The grand mean average of Ni concentration for worldwide soils is given as 5 mg kg^{-1}, which has been considered as background level of this trace metal [18]. The sediments of Yamuna are thus found to show a high degree of Ni contamination as evident from the enrichment factor found in the present study ranging from 8.8 to 9.9 (Table 2). This indicates substantial anthropogenic flux of Ni into the river. An earlier study shows Ni in the range of 14–46 mg kg^{-1} in Yamuna flood plains in Delhi. Over the last few years there has been an increase in Ni contamination, which may be partly attributed to developing industries and increased sewage discharge.

The aquatic plants showed 2.75 to 7.85 mg kg^{-1} of Ni. The requirement of this metal by plants as an essential micronutrient was found rather recently. A study by [23] reports that Ni added to the background level of soil by sewage or effluent is more available to the plants thus facilitating its rapid uptake. The aquatic plants can thus take up more Ni as pollution load increases.

Some important river sediments and water properties during the study period along the course of the river in Haryana through Delhi are depicted in Tables 3 and 4. Relationships of the trace metals with each other and with the water and sediment properties, when studied through correlation analysis indicated some statistically significant relationships, which are depicted in Table 5.

Table 5
Significant correlation in different analytes

Matrix		Correlation	R^2	Regression equation
X axis	Y axis			
Cd sediments	Cr sediments	0.674**	0.0345	$Y = -0.611X + 2.039$
Ni water	Ni sediments	−0.765**	0.627	$Y = -43.05X + 97.99$
Ni sediments	Cr water	−0.536*	0.291	$Y = -0.0004X + 0.039$
Cd sediments	Cd plants	0.683**	0.002	$Y = 0.005X + 0.491$
Cr water	Cr plants	0.691**	0.339	$Y = 134.49X + 0.463$
Ni sediments	Cr plants	−0.596*	0.351	$Y = -0.105X + 10.43$
Cd water	EC water	0.828**	0.028	$Y = -22.70X + 0.715$
Cd water	PO_4 water	0.840**	0.055	$Y = -4.562X + 0.1487$
Ni plants	OM sediments	0.503*	0.0274	$Y = -0.0025X + .3545$
Ni plants	SO_4 water	0.676**	0.0466	$Y = -0.0902X + 25.93$
Ni plants	Cl water	0.539*	0.0413	$Y = -0.675X + 97.94$
Ni sediments	OM sediments	0.582*	0.2699	$Y = 0.0522X + 4.56$

* $P < 0.01$.
** $P < 0.001$.

Amongst the metals, Cr and Cd showed a strong positive correlation indicating that they may be entering through common source and mutually favoring their adsorption on the sediments. Nickel in the sediments and water show a significant negative correlation indicating that removal of metal from water is strongly associated with adsorption into the sediments.

Uptake of Cd by the plants is positively correlated with Cd concentration in the sediment. Since Cd concentrations in water show very little variations, hence it is not desirable to correlate Cd uptake by plants to Cd levels in water. Uptake of Cr, on the other hand, is strongly correlated to Cr levels in the water but not to that of sediments. The Cr in sediments thus seems to be in more immobilized form, not available to the plants.

Out of the various other parameters of water and sediments studied viz. pH, EC, Cl^-, $SO_4{}^{2-}$, $PO_4{}^{3-}$, COD (for water) and organic matter (for sediment), only a few are found to be significantly correlated to heavy metal concentrations.

Cd concentrations in water bear a very strong positive correlation with electrical conductivity and $PO_4{}^{3-}$, levels of water. Other parameters do not significantly correlate with the concentrations of these trace metals in water.

Nickel concentrations in the plants are, however, positively correlated with Cl^- as well as $SO_4{}^{2-}$ levels in water and also with organic matter of sediments indicating commensurate addition of these pollutants from anthropogenic sources. Nickel concentra-

Table 4
Physico-chemical characteristics of water of river Yamuna flowing in Haryana and Delhi

Sampling station	Temperature (°C)	pH	Electrical conductivity (milli simians)	Chloride	Phosphate	Sulphate	COD
Y-01	20.9	7.8	0.4	18.82	0.002	53.40	30.80
Y-02	21.3	7.3	0.4	21.30	0.003	26.70	53.20
Y-03	22.2	7.6	0.4	21.30	0.004	19.58	39.20
Y-04	23.2	7.6	0.4	18.46	0.004	19.58	30.80
Y-05	24.3	7.7	0.4	19.82	0.005	20.47	19.60
Y-06	21.0	7.8	0.6	89.46	0.075	25.80	141.44
Y-07	22.2	8.2	0.4	63.90	0.036	17.80	27.20
Y-08	23.4	8.4	0.4	51.20	0.047	14.20	5.44
Y-09	22.8	8.6	0.4	52.54	0.043	28.40	59.58
Y-10	20.3	8.7	0.4	127.80	0.051	14.20	136.00
Y-11	21.9	7.8	0.7	89.46	0.112	27.14	86.40
Y-12	22.6	7.6	1.5	205.90	0.356	26.70	57.60
Y-13	23.8	7.9	1.6	229.94	0.50	30.30	28.80
Y-14	24.7	8.0	1.6	218.84	0.52	19.60	158.40
Mean ± S.D.	22.47 ± 1.32	7.93 ± 0.41	0.69 ± 0.49	87.77 ± 78.01	0.126 ± 0.187	24.56 ± 9.80	69.46 ± 49.26

All values in mg l^{-1} (except pH and where mentioned).

tions in the sediments are also correlated strongly with organic matter in the sediments.

Thus, there seems to be relatively more abundance of Ni on the surface of fine organic matter fraction of the sediments. Correlation between organic matter and have been usually reported. However, Fe, Cd and Cr do not show significant positive correlation with organic matter. There are other factors like pH which together with sediment organic matter might be affecting metal adsorption or desorption process due to acid or alkaline hydrolysis [24].

4. Conclusion

It is concluded from the present study that the river Yamuna flowing in Haryana has been significantly contaminated with Ni and Cd, the latter being of rather recent origin. While Ni enrichment is more or less uniform throughout the river, in case of Cd enrichment, there are certain sites showing a high value which, need particular attention for identifying and rectification of the source. Chromium contamination of Yamuna is moderate except that in two or three sites which are the downstream stations of dyeing, paint industries which need immediate attention for Cr removal from the waste waters prior to discharge. The anthropogenic contamination of the river Yamuna by Fe is negligible.

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References

[1] Central Pollution Control Board, Status Of Water Quality in India—2004, CPCB, New Delhi, India, 2004.
[2] J. Zhang, W.W. Huang, Dissolved trace metals in the Huanghe: the most turbid large rive in the World, Water Res. 27 (1) (1993) 1–8.
[3] S.A. Abbasi, N. Abbasi, R. Soni, Heavy Metals in the Environment, Mittal Publications, New Delhi, India, 1998.
[4] E.K. Lo, Y.S. Fung, Heavy metal pollution profiles of dated sediments cores from Hebe Haven, Hongkong, Water Res. 26 (12) (1992) 1605–1619.
[5] Central Pollution Control Board, Report on Water Quality Monitoring of Yamuna River. CPCB, New Delhi, India, 1996.
[6] K.M.N. Dakshini, J.K. Soni, Water quality of sewage drains entering the Yamuna, Delhi, Indian J. Environ. Health 21 (1979) 359.
[7] M. Ajmal, M.A. Khan, A.A. Nomani, Environmental monitoring of the Yamuna river-Part-1, Environ. Monit. Assess. 5 (1985) 205.
[8] M.E. Forago, A. Mehra, D.K. Banerjee, A preliminary investigation of pollution in river Yamuna, Delhi, India: metal concentration in river bank, soils and plants, Environ. Geochem. Health 11 (1989) 149.
[9] H.R. Sharma, D. Chhetry, A. Kaushik, R.C. Trivedi, Variability in organic pollution of river Yamuna I Delhi, J. Envrion. Pollut. 7 (3) (2000) 185–188.
[10] R. Khaiwal, Amena, Meenakshi, Monika, Rani, A. Kaushik, Seasonal variation in physico-chemical characteristics of river Yamuna in Haryana and its ecological best designated use, J. Environ. Monit. 5 (2003) 419–426.
[11] A. Kaushik, S. Jain, J. Dawra, R. Sahu, C.P. Kaushik, Heavy metal pollution of river Yamuna in the industrially developing state of Haryana, Indian J. Environ. Health 43 (14) (2001) 164–168.
[12] A. Kaushik, S. Jain, J. Dawra, P. Sharma, Heavy metal pollution in various canals originated from river Yamuna in Haryana, J. Environ. Biol. 24 (3) (2003) 331–337.
[13] M.J.L. Force, S.E. Fendorf, G.C. Li, G.M. Schneider, R.F. Rsenzweing, Heavy metals in the environment. A laboratory evaluation of trace elements mobility from flooding and nutrient loading of Coeur d'Alene river sediments, J. Environ. Qual. 27 (1998) 318–328.
[14] L.S. Clesceri, A.E. Greenberg, R.R. Trussell, Standard Methods for Examinations of Water and Waste Water, Publ. APHA, AWWA, WPCF, Washington, D.C., 1996.
[15] S.E. Allen, H.M. Grishma, A.P. Rowland, in: P.W. Moore, S.B. Chapman (Eds.), Chemical Analysis in Methods in Plant Ecology, Blackwell Scientific Publication, Oxford, 1986, pp. 285–344.
[16] A. Mehra, M.E. Fargo, D.K. Banerjee, A study of *Eicchornia crassipee* growing in over-bank flood plain soils of river Yamuna in Delhi, India, Environ. Monit. Assess. 60 (1) (2000) 25–45.
[17] B.T. Hart, Trace metals in natural waters. 1. Speciation, Chem. Australia 49 (1982) 260–265.
[18] B.J. Alloway, Heavy Metals in Soils, Blackie, London, 1990.
[19] A. Anderson, K.O. Nilson, Enrichment of trace elements from sewage sludge fertilizers in soils and plants, AMBIO 1 (5) (1972) 176–179.
[20] J.H. Martin, G.A. Knaeur, The elemental composition of phytoplankton, Geochem. Cosmochem. Acta 37 (1973) 1639.
[21] K.H. Wedepohl, The composition of the upper earth's crust and the natural cycles of selected metals in natural raw materials, natural resources, in: E. Merian (Ed.), Metals and their Compounds in Environment: Occurrence, Analysis and Biological Relevance, VCH, New York, 1991, pp. 3–17.
[22] R.K. Samasekhar, R.K. Ramaswamy, D.G. Arekal, Trace metal concentration of waters of south Indian rivers, Int. J. Environ. Stud. 20 (1982) 63–65.
[23] V.S. Zdanowicz, Determining the fates of contaminated wastes dumped in the New York Bight Apex by use of metal enrichment factors, Environ. Sci. Technol. 25 (1991) 1760–1786.
[24] W.W.S. Yim, W.C. Leung, Sedimentology and geochemistry of sea floor sediments in Tolo Harbor, Hong Kong—implications for urban development, Geol. Soc. Hong Kong Bull. 3 (1987) 493–510.
[25] S. Khan, M.A. Qureshi, J. Singh, Influence of heavy metals complexes on the mobility of some micronutrients through soil, Indian J. Environ Health 39 (3) (1997) 217–221.
[26] Alloway, B.J., Heavy metals in soils. Integrated Pollution Prevention and Control (IPPC) Best available techniques reference document on the production of iron and steel. Publ: EC European IPPC Bureau. John Wiley and Sons, Inc. New York, ISBN 0470215984 EC (1999) 370 pp.